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Measuring Observers' Visual Acuity Through Night Vision Goggles

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ABSTRACT

Use of night vision goggles (NVGs) for military applications has grown steadily over the past 30 years. Each successive NVG model represents some kind of improvement in terms of size, weight, ruggedness, gain, noise, spectral sensitivity, field-of-view or resolution. The primary focus of this paper is the determination of NVG resolution. Many methods have been devised to measure the resolving power of NVGs and each method has with it an associated variance or accuracy of measurement. This variance is most likely caused by several sources including observer visual capability (since most methods involve visual observations and judgement to assess NVG resolution). The main purpose of this paper is to present the different methods that have been used to assess NVG resolution and to determine to what extent observer visual capability limits the accuracy of NVG resolution measurement. This study uses a methodology that measures an observer's psychometric function when viewing through NVGs (percent correct detection as a function of spatial separation) to determine their visual acuity using probit analysis.

INTRODUCTION and BACKGROUND

Night vision goggles (ITT) allow an observer to see objects that are illuminated by very low amounts of light energy by greatly amplifying the light level. Present generation NVGs have a gain (as measured by the Hoffman ANV-120) of 6000 or more which means that for an object illuminated by a 2856K color temperature light source the NVGs present a luminance that is 6000 times brighter than the object viewed directly. However, the image intensifier tubes that are the heart of the NVGs also have an automatic brightness control which limits the output luminance. For present generation NVGs this maximum average output luminance is on the order of 2 to 4 foot-Lamberts. Since visual acuity depends on light level it is apparent that the level of detail that can be seen through the NVGs depends on the illumination level on the target scene. This becomes a factor in determining the resolution of NVGs.

The term "resolution" is defined (the definition of interest to this topic) by Webster's Ninth New Collegiate Dictionary as "the process or capability of making distinguishable the individual parts of an object, closely adjacent optical images, or sources of light." The same dictionary defines "visual acuity" as "the relative ability of the visual organ to resolve detail that is usually expressed as the reciprocal of the minimum angular separation in minutes of two lines just resolvable as separate and that forms in the average human eye an angle of one minute." It is apparent from these two definitions that "resolution" and "visual acuity" are somewhat connected but are not quite the same thing, especially when we refer to the "resolution" of the NVGs. The primary reason for having a parameter such as resolution is to try to describe the capability of the NVG. However, all current widely used methods of measuring NVG resolution involve the use of human observers and vision. This has both good and bad points. The good point is that the NVGs are intended to be used with human vision in operation; so using vision as the means to assess NVG resolution seems to make sense. The bad point is that when one uses human visual capability as an integral part of a measurement procedure one may end up with increased variance due to individual differences or dynamic shifting of human visual threshold. The purpose of the research described herein is to determine the extent of human visual acuity variance when viewing through NVGs by using "frequency of seeing" curves. This is a time-consuming approach and is not suitable as a routine method for characterizing NVG resolution; but it does provide some insight into limitations of other methods used to measure NVG resolution.

There is a subtle but very real difference between "NVG resolution" and "visual acuity through NVGs." This can be demonstrated by the following example. Suppose that some day advanced technology produces a "super" NVG capable of presenting details down to a tenth of a minute of arc. If vision is used to assess these "super" NVGs we would get a reading of about 1 minute of arc since that is the limit of visual capability; even though the NVGs were presenting details one tenth of this size. Thus, in this case, what is being measured is actually "visual acuity through NVGs" and not the actual "NVG resolution." As long as NVG capability is worse than human visual capability there is not a significant difference between the two. However, even with today's NVGs the difference between "NVG resolution" and "NVG visual acuity" can be significant at low light levels. Although the measurement methods described in the following section are used to measure "NVG resolution" most of them actually measure "NVG visual acuity."

METHODS USED TO MEASURE NVG RESOLUTION

Snellen Letter Charts

The Snellen eye chart is frequently used by optometrists to assess patients' visual acuity. The chart displays rows of letters starting with a very large size (20/200) and stepping down to the smallest (20/10). A measured Snellen acuity of 20/40 means that the person sees certain chart letters at a 20 foot viewing distance as well as a person with normal sight sees the same chart letters at 40 feet. The visual acuity score can be converted to minutes of visual subtended angle by taking its reciprocal (for example 40/20) and then dividing to get (2) minutes of arc (MOA). Miller, Provines, Block, Miller and Tredici (1984) used the Snellen eye chart to measure visual acuity through NVGs. The tumbling E (used by Wiley, 1989; Levine and Rash, 1989) chart has also been used to measure visual acuity through NVGs. Some researchers (Kotulak and Rash, 1992) prefer to use the Bailey and Lovie (1976) eye chart which has logarithmically sized letters.

Limiting Resolution

Limiting resolution is defined as the spatial frequency at which the modulation transfer function (MTF) of the NVGs (Stefanik, 1994) and the visual threshold function or VTF (Campbell and Robson, 1968; Task, 1979) intersect (see Figure 1). This intersection point occurs at the highest spatial frequency that the NVG can transmit with sufficient contrast that the human eye can see it. This spatial frequency can be converted to an equivalent Snellen acuity or other convenient resolution unit. (Barfield and Furness, 1995). Though the concept itself is straightforward, there are underlying problems associated with its implementation. The MTF of an NVG is difficult to measure because of the low light level and the scintillation. Also, the VTF has a certain amount of variance associated with its measurement since it involves human vision. It order to accurately predict the limiting resolution using this approach one would need to measure the observers VTF for the same color, luminance levels, and noise levels that occur in the NVG. Both the VTF and the MTF measurements are time consuming processes and not suitable for routine testing. In addition, the variance associated with both the MTF and the VTF mean that there will be a corresponding uncertainty regarding the location of the intersection of these two. This results in a fairly significant variance in the final limiting resolution determination.

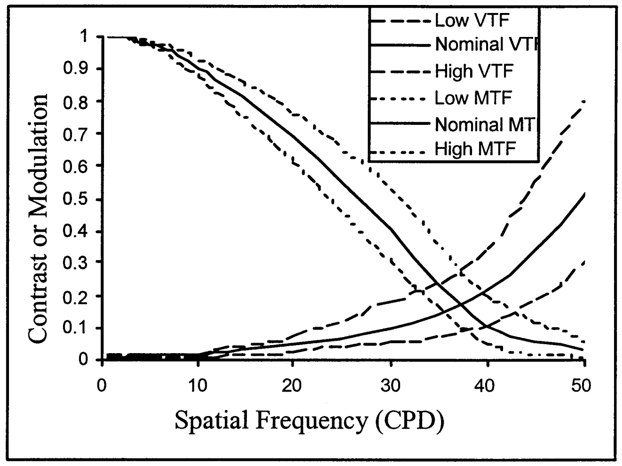

Figure 1. Idealized NVG MTF (upper thick solid line) and VTF (lower thick solid line); their intersection defines limiting resolution. Note the range (about 33 cpd to 43 cpd in this example) of possible limiting resolution values due to the variance (the upper and lower dashed lines) in the MTF and VTF measurements.

1951 AF Tri-Bar Target

One of the most frequently used resolution test standards is the 1951 Air Force tri-bar target (see Fig. 2) which was originally developed as a tool to evaluate the optical performance of airborne reconnaissance systems (MIL-HDBK-141). This target pattern contains seven groups having six elements each. Each element is comprised of a pair of three-bar patterns, one pattern is vertically oriented and the other is larger by a factor of the 6th root of 2 (about 1.1225) than the next smaller element. This means the first element of each group is exactly twice as large as the first element of the next smaller group. The original 1951 USAF tri-bar target was designed with Group 0, Element 1 set to one line pair per millimeter. However, in order to use this pattern to evaluate NVGs the basic pattern has been greatly magnified as a wall chart. A conversion factor must be devised to convert from the Group and Element number to NVG resolution. Most of the time NVG resolution is given as a Snellen acuity equivalent with the conversion being 1 minute of arc angular subtense of a bar width corresponds to 20/20 Snellen visual acuity. A Snellen acuity of 20/40 would correspond to a bar width of 2 minutes of arc and so on.

NVG resolution is determined by having a trained observer view the tri-bar pattern under specified illumination conditions (which may be between overcast starlight up to full moon illumination equivalent) and then state which Group and Element number he/she can "resolve." This is then converted to a Snellen acuity equivalent using the conversion assumptions stated above. When doing NVG evaluations agencies may have 3 trained observers whose responses to this test are averaged to determine the "resolution" of the night vision goggles. Although the 1951 tri-bar target pattern has proved to be very useful over the years in comparing lens systems it still has a certain amount of variance due to differences in observer criteria as to when the tri-bars are "resolved" (Farrell and Booth, 1984, p. 3.1-41, item 18). Studies using the tri-bar pattern have shown observer "resolution" discrepancies of as much as 60%. (Farrell and Booth, 1984, p. 3.1-41 item 18).

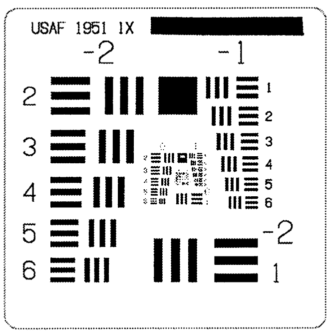

Figure 2. US Air Force 1951 tri-bar resolution chart.

3X3 Square-Wave Target Array
The 3x3 square-wave target array (Task and Genco, 1986) was developed about 1989 as a means for pilots to do a quick verification that their NVGs were operating correctly and were capable of resolving detail to a specified level. This chart has several features that set it apart from the 1951 AF target. The chart has nine square-wave patterns, arranged in a 3x3 array as shown in Figure 3. For its standardized viewing distance of 20 ft., each pattern was sized to equal specific Snellen values of 20/20 through 20/60 in increments of five. Their locations and orientations within the array were randomized. To increase the number of randomized grating orientations for a repeated measurements test, the chart is simply rotated to any one of its four orientations which has the effect of quickly changing grating locations and orientations within the 3x3 array. Each chart orientation was numbered one, two, three and four which keyed it to legends on the back of the chart for quick acuity reference. Charts having different levels of contrast were also made.

The chart was placed at a 20 ft. viewing distance and illuminated with a 2856K color temperature illumination source that could be adjusted to various desired illumination levels. After adjusting the NVGs, the trained observer examines pattern, reporting which grating structure could be resolved and its orientation (vertical or horizontal). After all of the rows are viewed, the chart is rotated to a new orientation and the test is repeated. With this kind of chart, repeated measurements can be quickly made and the results, which are in Snellen acuity, can be directly compared to what the NVGs should be capable of resolving. This method has been successfully used for many years and has been adopted as the standard test chart that squadrons use to perform preflight NVG adjustments and to insure that the goggles are performing optimally. However, the step sizes between patterns are relatively large making this pattern unsuitable for comparing the capability of different NVGs that are somewhat close in their resolving power.

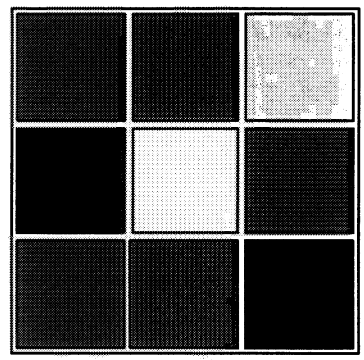

Figure 3. The 3x3 NVG chart (US Patent 4,607,923).

Step-Back Method
In an effort to refine the square-wave grating pattern to obtain smaller step sizes between resolutions a variation was developed and constructed (see Figure 4) containing six pairs of vertically and horizontally oriented square-wave gratings (Donohue-Perry, Task and Dixon, 1994). While looking through the NVGs at the pattern from a distance of 30 ft, the observer selected the smallest resolvable target pair. Then the observer would slowly step backwards until the selected target pair was no longer resolvable. The observer then stepped forward until the square-wave pair could barely be resolved. This final viewing distance was then used to calculate the exact Snellen acuity of the selected target pattern. The spatial frequencies of the square-wave patterns were sufficiently close together in spatial frequency that the observer would not have to step back more than 3 ft (10% of the baseline viewing distance) thereby minimizing the effect of possible objective lens misfocus.

The step-back method eliminated the problem of step sizes between target patterns by making the angular subtense of the square-wave pattern a continuous variable. When doing an NVG resolution evaluation measurements were typically repeated several times (e.g. 5) for 3 trained observers and then averaged to determine the final value.

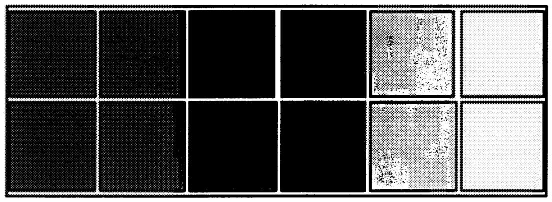

Figure 4. Example of the square-wave chart used in the step-back method.

Landolt C

Another assessment method uses Landolt C stimuli (National Academy of Sciences, 1980). The Landolt C is a perfectly circular C (no serifs) that has a specified contrast and gap size. The gap size is varied as is the orientation. The observer's task is to detect the orientation of the gap. Pinkus and Task (1997) used closely sized Landolt C stimuli in a two-alternative, forced-choice (2AFC) method to determine visual acuity through NVGs as a function of night-time ambient illumination levels. A computer executed the 2AFC (gap seen up or down), Step Program adapted from Simpson (1989). Based on the observer's last response, the program selected the specific gap size (smaller or larger) of the next Landolt C to be presented, according to *a priori* rules inherent in the algorithm. This method allowed relatively efficient convergence to a threshold acuity usually within 10 to 35 trials. The step method yielded reasonable results but informal repeatability tests found that the observer's scores varied from day to day. These variations could be due to a number of variables: working at threshold levels, NVG drift, good guessing in the 2AFC method, fatigue, eye strain, sinus headaches and so on.

METHOD

Psychometric Function of Acuity Through NVGs

Probit analysis (Finney, 1980) provides a method by which to fit a smooth s-curve through empirically derived probabilistic data. The threshold acuity of a trained observer may be determined by first measuring the probability of correct responses (the location of a Landolt C's gap) as a function of gap size. In order to reduce the effects of "good guessing", we used a four-alternative, forced-choice (4AFC) presentation of Landolt C's where the observer had to state if the gap was oriented up, down, left or right. The probabilities of the resulting s-curve, or ogive function, were then converted to z-scores and a straight line was fit to the data. When the z-score data were converted back to their equivalent probabilities and replotted, the line formed a smooth, s-shaped curve through the data. Depending on the number of possible outcomes in a particular forced-choice paradigm, the floor of the curve was usually near chance levels (25% for 4AFC). As gap size increased, the probability of correct detection of its orientation increased until it asymptotes at the 100% correct level. Though arbitrarily selected, the acuity (or any other quantity) is conventionally defined as the value that corresponds with the probability point that is half way between chance and 100% correct (Brown, Galanter, Hess and Mandler, 1962). This point is at the 62.5% probability level for the 4AFC presentation. The present study derived visual acuity through NVGs by measuring this psychometric function.

Participants

The three participants in this study were highly trained psychophysical observers, two males and one female, ranging in ages from 36 to 47 years.

Apparatus and Stimuli

The study utilized a set of ITT Model F4949C (serial #0356) NVGs that had P-43 phosphor (green) image intensifier tubes. The goggles had a gain (Hoffman) of about 5000 as measured by a Hoffman ANV-120 Night Vision Goggle Test Set. With the room lights off and the NVGs on, the observer first adjusted the interpupillary distance (IPD) of the goggles. Next they adjusted the eyepiece lenses by looking at the dark ceiling with the goggles and focusing until the scintillation looked sharp. Objective lenses were then focused by viewing an approximately one-half moon illuminated NVG resolution chart (see Fig. 2) composed of square-wave gratings (Task and Genco, 1986).

All observations were made in a light-tight room. The observer sat in a chair behind a table with their eyes 9.14 m (30 ft) from the stimulus target. The NVGs were held in a mount at the proper height for viewing while the observer was seated. The goggles were powered using a regulated external power supply.

The stimuli were high contrast (70% Michelson) Landolt C's (National Academy of Sciences, 1980) printed using a high resolution photo-grade laser printer. After the study, the observers' data were converted to Snellen acuity (20/xx). The C's were mounted on 18 x 18 cm (7 x 7 in.) foam board. For presentation, the C was placed onto a larger surround board 61 x 61 cm (24 x 24 in.) that matched the high contrast Landolt C background reflectance. The background board was held on an easel and had a small ledge that held the letter C in the center. This ledge was invisible when viewed through NVGs. The C was then placed by the experimenter onto the ledge with the gap oriented either up, down, left or right. The experimenter's station was to the side of the stimulus easel.

An adjustable 2856K color temperature incandescent lamp (MIL-L-8576A, 1986) was used to produce the different illumination levels. Apertures were used to vary illumination intensity without affecting the color temperature. Table 1 shows the five illumination levels and the five corresponding luminance outputs from the NVG eyepieces used for the study. The lowest level is approximately equivalent to 1/100th full moon (RCA Electro-Optics Handbook, 1974). Each succeeding level is approximately double that of the previous level to form the five illumination levels. Another lamp, set to about one-half moon illumination of $1.3x10^{-1}$ lux ($1.2x10^{-2}$ fc) was used to illuminate an NVG resolution target (Task and Genco, 1986) during pretest goggle focusing.

Table 1. The five illumination levels used in the study and their corresponding NVG output luminances.

Illumination on Landolt C	NVG Output Luminance
$8.61x10^{-4}$ lux ($8.00x10^{-5}$ fc)	0.356 nit (0.104 fL)
$1.72x10^{-3}$ lux ($1.60x10^{-4}$ fc)	0.709 nit (0.207 fL)
$3.44x10^{-3}$ lux ($3.20x10^{-4}$ fc)	1.398 nit (0.408 fL)
$6.89x10^{-3}$ lux ($6.40x10^{-4}$ fc)	2.720 nit (0.794 fL)
$1.38x10^{-2}$ lux ($1.28x10^{-3}$ fc)	4.324 nit (1.262 fL)

Procedure

First the observer was partially dark adapted to the goggle output luminance for about 10 minutes. The stimulus was blocked from the observer's view by the experimenter when the stimulus was placement onto the easel. The experimenter asked the observer if he or she was ready, unblocked the stimulus for about 4 seconds, then blocked it again. The observer had to respond either "up, down, left, right" to indicate the orientation of the C. No feedback was given to the observer. The experimenter then removed the stimulus and placed the next stimulus size, at a randomized orientation, onto the easel. The procedure was repeated until all 112 stimuli were presented requiring about 55 minutes. One lighting level was tested per day for each observer.

RESULTS

Each of the four Landolt C orientations was repeated four times yielding 16 trials per Landolt C size. Each observer performed 16 trials for each combination of Snellen acuity and illuminance ($8.61x10^{-4}$, $1.72x10^{-3}$, $3.44x10^{-3}$, $6.89x10^{-3}$ and $1.38x10^{-2}$ lux). There were seven levels of Landolt C sizes used for each level of illuminance. The acuity ranges (Landolt C sizes) used for each illumination level were selected from pilot data. Four orientations, repeated four times, for seven gap size values, over five levels of illuminance and using three observers yielded a total of 1680 data points for the study. The percent of trials correctly identified was determined for each combination of observer, illuminance and acuity (N=16).

Chance alone would result in 25% correctly identified trials. It is assumed that percents that are less than 25% would approach 25% given a sufficient number of trials. The percents were transformed to adjust for chance. The procedure for this transformation is as follows:

Let: P = percent of correct trials
P_A = percent of correct trials adjusted for chance

(1) if $P < 25$ then $P = 25$
(2) $P_A = (P-25)*100/75$

Certain percents were not used for modeling. The rational for selecting percents used for modeling was to start with the *last value = 0* (if applicable) and end with the *first value = 100* (if applicable).

These percents were converted to normal equivalent deviates[10] (NED). An NED is the value of a standard normal variable whose cumulative probability (expressed as a percent) would equal the percent adjusted for chance. Since an NED can not be computed for 0% or 100%, 0% was set equal to 1% and 100% was set equal to 99%. The NED values were used as the dependent variable in a linear regression with acuity (gap size) as the independent variable (a linear relationship is assumed).

The estimated linear equation, $NED = b_0+b_1*acuity$, was expanded to the full range of acuity used for each illuminance. The predicted NED was then transformed back to percents. For each illuminance and observer, the acuity that corresponded with predicted 50, 75 and 95 percent correct trials adjusted for chance were determined. Results are shown in Table 2.

Table 2. Snellen acuity values (20/xx) corresponding to predicted 50, 75, and 95 percent correct trials adjusted for chance, for each illuminance and observer.

Illuminance (lux)	Obs	50%	75%	95%
$8.61x10^{-4}$	S1	30.6	36.1	44.0
	S2	35.0	40.0	47.2
	S3	32.1	36.0	41.6
$1.72x10^{-3}$	S1	26.0	29.0	33.3
	S2	23.2	26.0	30.1
	S3	27.7	30.4	34.2
$3.44x10^{-3}$	S1	24.8	27.9	32.4
	S2	21.8	25.8	31.5
	S3	23.9	27.8	33.3
$6.89x10^{-3}$	S1	22.0	26.1	32.1
	S2	23.5	27.4	33.0
	S3	22.5	24.0	26.2
$1.38x10^{-2}$	S1	23.0	25.1	28.0
	S2	21.1	23.3	26.5
	S3	21.1	23.7	27.4

The same procedure for determining the predicted percent of correct trials adjusted for chance that was performed for each illuminance and observer was also performed for each illuminance averaged across observers. Table 3 contains the percent of trials correctly identified for each combination of illuminance and acuity. Table 4 contains the percent of correct trials adjusted for chance. Table 5 contains the acuity values corresponding to predicted 50, 75 and 95 percent correct trials adjusted for chance. Figure 5 contains plots of NED regressed n acuity for each illuminance and Figure 6 contains plots of the predicted percents.

Table 3. Percent of correct trials (N=48) for each illuminance and Snellen acuity (20/xx).

Illuminance (lux)	Acuity (20/xx)	Percent Correct
8.61×10^{-4}	30.6	58
	32.5	54
	34.4	77
	36.3	77
	38.2	83
	40.1	79
	42.0	96
1.72×10^{-3}	19.1	29
	22.9	54
	26.7	65
	28.6	75
	32.5	96
	36.3	100
	38.2	98
3.44×10^{-3}	19.1	42
	22.9	56
	26.7	83
	28.6	81
	32.5	96
	36.3	100
	38.2	100
6.89×10^{-3}	19.1	46
	21.0	48
	22.9	65
	24.8	71
	26.7	83
	28.6	92
	30.6	96
1.38×10^{-2}	19.1	40
	21.0	69
	22.9	71
	24.8	85
	26.7	92
	28.6	98
	30.6	98

Table 4. Percent of correct trials (N=48) adjusted for chance, for each illuminance and Snellen acuity (20/xx). Percents in *italics* were not used for modeling.

Illuminance (lux)	Acuity (20/xx)	Percent Correct
8.61×10^{-4}	30.6	44
	32.5	39
	34.4	69
	36.3	69
	38.2	78
	40.1	72
	42.0	94
1.72×10^{-3}	19.1	6
	22.9	39
	26.7	53
	28.6	67
	32.5	94
	36.3	100
	38.2	*97*
3.44×10^{-3}	19.1	22
	22.9	42
	26.7	78
	28.6	75
	32.5	94
	36.3	100
	38.2	*100*
6.89×10^{-3}	19.1	28
	21.0	31
	22.9	53
	24.8	61
	26.7	78
	28.6	89
	30.6	94
1.38×10^{-2}	19.1	19
	21.0	58
	22.9	61
	24.8	81
	26.7	89
	28.6	97
	30.6	97

Table 5. Snellen acuity values (20/xx) corresponding to predicted 50, 75, and 95 percent correct trials adjusted for chance, for each illuminance.

Illuminance (lux)	50%	75%	95%
8.61×10^{-4}	32.6	37.5	44.7
1.72×10^{-3}	25.8	28.8	33.2
3.44×10^{-3}	23.6	27.4	32.8
6.89×10^{-3}	22.8	26.2	31.0
1.38×10^{-2}	21.5	24.3	28.4

The data presented in this results section up to this point were all collected as part of experiment 2 which used 3 trained observers. In preparation for experiment 2, data were collected on 2 observers using the same methodology. Table 6 and Figure 7 shows the data for these 2 observers for the 2 data collection sessions. This provides some indication of the repeatability of the procedures described herein.

Table 6. Visual acuity results for 50% probability level for 2 observers and 2 experiments.

		Illumination Level (lux)			
Observer	8.61E-04	1.72E-03	3.44E-03	6.89E-03	1.38E-02
O2-1	35.2	25.6	24	23.3	21.2
O2-2	35.0	23.2	21.8	23.5	21.1
O3-1	36.1	28.3	28.5	23.8	20.5
O3-2	32.1	27.7	23.9	22.5	21.1

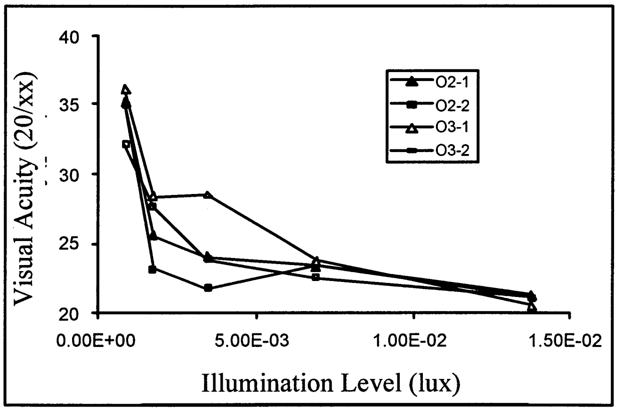

Figure 7. Comparison of visual acuity vs. illumination for 2 observers (S2 and S3) for two experiments.

DISCUSSION

The results of Table 5 showing averaged (across the 3 observers) visual acuity data for the 5 illumination levels does indicate the satisfying result that one would expect: namely, that visual acuity gets worse (higher number) as illumination level is reduced. This result holds for the 3 different probability levels shown in Table 5 (50%, 75%, and 95%). However, this does mask the difference in visual acuity measured for the different observers. Table 6 shows a comparison of the 50% probability visual acuity for 2 of the observers that participated in both this main experiment and a pilot experiment done earlier to establish procedures. It is apparent from Table 6 that there is a fairly large difference between the 2 observers at the lower illumination levels. At higher illumination levels the observer's performance converges both between the observers and between the two data collection sessions (experiment 1 and 2) graphically shown in Figure 7.

It is apparent from the graphs of Figures 5 and 6 that more presentation trials are needed to improve the smoothness of the "frequency-of-seeing" curves. However, the basic approach appears to be sound and should provide a good baseline for assessing visual acuity using other, less time-consuming, methodologies. Equipment and procedures are being designed to semi-automate data collection to obtain the "frequency-of-seeing" curves faster. Once this is done, we expect to compare NVG visual acuity using some of the widely used methodologies, such as the tri-bar chart and the square-wave chart, to specific probability levels on the frequency-of-seeing curves. The procedure would be to establish a frequency-of-seeing curve for a particular observer using a particular NVG. Then measure the NVG visual acuity of the same observer using the tri-bar chart and the square-wave chart. By comparing each of these NVG visual acuities to the frequency-of-seeing curve it should be possible to determine what probability level equates to the tri-bar chart procedure and the square-wave chart procedure.

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H. Lee Task has been employed as a research scientist for the US Air Force since 1971. He has served as chief scientist for the Armstrong Aerospace Medical Research Laboratory (prior to its reorganization and disestablishment in 1991) and is presently a senior scientist at the Visual Display Systems Branch of the Human Engineering Division, in the Armstrong Laboratory's Crew Systems Directorate, at Wright-Patterson AFB, Ohio. He is currently involved in research and development in the areas of helmet-mounted displays, vision through night vision goggles, optical characteristics of aircraft windscreens, vision, and display systems. He has a BS Degree in Physics (Ohio University), MS degrees in Solid State Physics (Purdue, 1971), Optical Sciences (University of Arizona, 1978), and Management of Technology (MIT, 1985) and a PhD in Optical Sciences from the University of Arizona Optical Sciences Center (1978). During his career he has earned 36 patents and has published more than 80 journal articles, proceedings papers, technical reports, and other technical publications. He is a member of the Human Factors and Ergonomics Society (HFES), the American Society for Testing and Materials (where he is chairman of Subcommittee F7.08 on Aerospace Transparencies and is a Fellow of the Society), the Association of Aviation Psychologists, SAFE association, the Society for Information Display (SID), and SPIE (the optical engineering society). He has served as reviewer for papers in SID, and HFES. Lee is currently the Editor of the *SAFE Journal.*